## Signature Page (Assessment Team Members)

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Steven G. Labbe

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Colin Bidwell

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Basil Hassan

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Dan Dumbacher

# 1 List of Team Members, Ex Officio Members, Advisors, Observers, and Others

Four Debris Transport Analysis (DTA) Peer Reviews were conducted during the period from September, 2003 through December 2004.  The reviews are listed with the designated NESC subject matter experts in attendance at each review.  Note that the initial DTA peer review was conducted just prior to the formation of the NESC, however the review team did include several subject matter experts subsequently recognized by the NESC.  In addition, the follow on peer reviews addressed the progress on recommendations made during this initial review. Therefore the results of the initial review are included in this document for completeness.

> I.      *Initial DTA Peer Review – S. Labbe, S. Bauer, B. Hassan*
> *(not an official NESC activity)*
> II.     LH2 Flange Foam DTA Peer Review – C. Bidwell, B. Hassan
> III.    Lift Off Debris DTA Peer Review – D. Dumbacher
> IV.     Monte-Carlo/Probabilistic DTA Peer Review – S.Labbe, C. Bidwell, B. Hassan

# 2 Executive Summary

Outside the board direction to provide support to a planned Debris Transport Analysis (DTA) Peer Review was received from the NESC director Ralph Roe.  This was in response to Mr. Roe's attendance at the Space Flight Leadership Council meeting (Feb. 2004) at which the Debris Transport Analysis was one of the items addressed.  The NESC Flight Sciences SPRT was tasked to identify and provide subject matter expert support to the SSP Debris Transport Peer Review.

Support at the LH2 Flange Foam DTA Peer Review was provided via GRC/Colin Bidwell, an expert in particle transport analysis, based on his aircraft icing modeling development.  This review was the second in a series of ongoing DTA peer reviews.  The initial DTA peer review had been conducted Sept. 30 to Oct. 1, 2003.  Recommendations from this initial review were traced and a follow up review was planned.  However, the LH2 Flange Foam review was specific to the redesign recommendation of this critical External Tank (ET) closeout and therefore this review was not considered as the recommended follow up review.  The DTA work and development has continued right through the extended RTF activities. Two additional peer reviews of the DTA were ultimately conducted.

The NESC provided subject matter expert support at each of these reviews.  The NESC designees served as members of the Space Shuttle Program (SSP) designated peer review boards.  The support was in the form of active participation in the Peer Review; assessment

of the SSP assembled peer review team as the right team (independent review, proper expertise, etc.); and assessment of the decisions being made with concurrence or non-concurrence.  It should be noted that the NESC did not specifically develop stand alone findings for NRB approval.  There were significant findings and recommendations generated from each of the peer reviews.  Follow up on these recommendations was monitored at subsequent SSP Aero Panel teleconferences, SSP Debris Summits and debris Design Verification Reviews (DVR) as well as the follow on DTA peer reviews.

Major findings and recommendations included
    Peer Review 1: Established that an appropriate balance between urgency and fidelity has been achieved in the DTA.  That the planned enhancements and validation efforts would improve the results and that more must be completed prior to Return-to-Flight (RTF).  Peer review resulted in an extensive test validation effort addressing all aspects of the DTA.
    Peer Review 2: Concurred with the recommendation to redesign the ET LH2 Flange Foam Closeout.  Additionally recommended that more physics be introduced into the DTA modeling
    Peer Review 3: Focus on the Lift-Off DTA (LODTA).  Identified the future work necessary to address the limitations and subsequent methodology implementation.  Completion of this work is necessary before the LODTA can be used to support debris flight rationale.
    Peer Review 4: Concluded that the Monte-Carlo DTA approach could be used to more realistically apply the uncertainties in the SSP capability vs. environment calculations.  Recommended further (proper) development of the probabilistic methodology for application to problematic debris flight rationale areas.

Any further DTA assessments or reviews will be conducted as part the 05-010-E ITA to Peer Review the Flight Rationale for Expected Debris.  A summation assessment of the current DTA methodology will be provided in the 05-10-E documentation.

# 3   Consultation Plan

NESC designees served as members of the SSP appointed peer review boards.  The support was in the form of active participation in the peer review; assessment of the SSP assembled peer review team as the right team (independent review, proper expertise, etc.); and assessment of the decisions being made with concurrence or non-concurrence.  The NESC did not plan to specifically develop stand alone findings, nor where any provided.  The findings from the peer reviews were communicated directly to the SSP Systems Engineering & Integration (SE&I) office.  Follow up on recommendations was monitored and assessed through planned SSP Aero panels, Debris Summits and TIMs, Design Verification Reviews and the subsequent Peer Reviews.

# 4   Description of the Problem, Proposed Solutions, and Risk Assessment

Four separate DTA peer reviews were conducted from Sept. 30, 2003 through Dec. 16, 2004.

*Initial DTA Peer Review (1) - NASA JSC - Sept 30 to Oct 1, 2003*
   *(Note: not official NESC activity)*

Provide technical review of the SSP debris transport analysis (DTA) process in order to identify strengths and weaknesses in the analysis process and provide recommendations on how to increase the accuracy and completeness of the process. The DTA process begins as the debris is liberated from a location on the Space Shuttle Launch Vehicle (SSLV), such as the External Tank (ET) and ends as the debris impacts another part of the SSLV, such as the Orbiter. The rationale behind the debris failure to stay attached and the effect of the foam impact on the Orbiter was not a part of this review although a status of each was reviewed.

LH2 Flange Foam DTA Peer Review (2) – NASA JSC – Feb. 26-27, 2004

The debris transport peer review team was expected to critically review the information provided and make a determination on the adequacy of the transport process to accurately represent debris motion in the presence of the launch vehicle at near transonic speeds.  This includes the process for acquiring initial conditions from the source, transporting the debris to the impact zone, and providing the impact conditions to the target. Of particular importance is the team's evaluation of the ET LH2 intertank foam zone of impact. The team findings will be documented and presented to the head of the Space Shuttle Systems Integration Program.

Liftoff DTA Peer Review (3) – NASA MSFC – Nov. 17-18, 2004 – Action from pre-DVR

Assess the development of the inputs, analysis and trajectory codes for Liftoff Debris Transport which determine debris trajectories and impacts from steady state flow fields of shuttle stack on pad, *pre-launch*, with just SSME's running, SSME's and Solid Rockets ignited, and vehicle in flight for several flight ascent trajectory points from liftoff until launch tower clear.  Recommend further development and application of methods established to support development of RTF rationale.

Monte-Carlo / Probabilistic DTA Peer Review (4) – NASA JSC – Dec. 15-16, 2004

Primary goal was to evaluate the Monte-Carlo type uncertainties analysis and the quantification being used to assess DTA uncertainties as well as the current process for Monte-Carlo DTA from source to impact.  A secondary goal was to evaluate the proposed methodology being used for statistical analysis leading to impact conditions probability. The team findings will be documented and presented to the head of the SSP Systems Engineering & Integration Office

# 5 Data Analysis

Peer reviews were attended by subject matter experts who actively participated in the real time process. Inputs from experts were included directly in the peer review team reports to the SSP SE&I office. No specific NESC findings were established.

# 6 Findings, Root Causes, Observations, and Recommendations

*Initial DTA Peer Review (1) - NASA JSC - Sept 30 to Oct 1, 2003 (not official NESC activity)*

This first peer review was conducted during the initial efforts of the SSP to conduct DTA on a pre-defined list of 15 critical debris sources. The review was focused on the DTA aspect of the overall debris problem. Debris particle aerodynamics, release conditions, CFD generated transport flow fields, model geometric fidelity, debris dynamics and assumptions on impact conditions were reviewed. In conclusion the peer review team established that an appropriate balance between urgency and fidelity has been achieved in the DTA. That the planned enhancements and validation efforts would improve the results and that more must be completed prior to Return to Flight (RTF). Specific findings and recommendation charts presented to the SSP SE&I office are included in Appendix A.

As a result of this peer review an extensive effort on verification and validation of debris particle shape, aerodynamics and initial conditions was initiated. Additionally an extensive wind tunnel testing and CFD flow field evaluation was also initiated with the intent of validating the flow field velocity. Finally sensitivity analyses were identified to be performed to establish and define the critical parameters. For the overall process it was recommended that an improved system engineering integration and communication (between debris source, DTA and vulnerable structure technical areas) be established to raise transport team effectiveness.

*It should be noted that the results of these validation activities have been reviewed at several SSP Debris Summits, DVRs and Technical Interchange Meetings. A summation assessment of the current DTA methodology will be provided as part of the 05-010-E ITA to Peer Review the Flight Rationale for Expected Debris.*

LH2 Flange Foam DTA Peer Review (2) – NASA JSC – Feb. 26-27, 2004

This Peer Review was an interim peer review which concentrated on the LH2 flange foam debris transport which had recommended a redesign of this external tank closeout and consequently a subsequent delay in return to flight. The peer review committee found the analysis process reasonable and concurred with the findings that the ET be redesigned. Additionally, the committee felt strongly that more physics should be added into the DTA (e.g. Debris Particle Lift equations) and that more validation should be completed. It was

left to the Transport Team to determine the method of validation. Specific findings and recommendation charts presented to the SSP SE&I office are included in Appendix B. C.Bidwell/GRC was the NESC designee on the Peer Review panel. His observations are documented in formal letter (dated April 20, 2004) enclosed as Appendix C. He was in agreement with the findings from the committee and the Transport Team that the ET be redesigned to eliminate the potential LH2 flange foam debris source.

*Note: The Peer Review team recommendation supported the SSP decision to redesign the LH2 Flange foam closeout, a critical debris source and resulted in one of the RTF postponements from September 2004 to NET February 2005.*

## Liftoff DTA Peer Review (3) – NASA MSFC – Nov. 17-18, 2004 – Action from pre-DVR

The Lift off Debris Transport Peer Review addressed the recent development of a DTA model incorporating gravity, wind and plume driven debris transport with a CAD model of the SSLV on-pad configuration and CFD solutions for the flow field at various time slices from pre-launch, through SSME startup, SRB ignition, SSLV liftoff to tower clear.
At the time of the peer review validation of the analysis was being defined. The results of the Lift-Off DTA were considered only good for qualitative assessment. The focus of the Peer Review was to assess the capability of the current methodology to support Debris Flight Rationale and to identify the necessary verification and validation. Dan Dumbacher/MSFC was the NESC designee on the Peer Review panel. His observations are documented in an e-mail (dated Nov. 18, 2004) enclosed as Appendix D. It was noted that the Transport Analysis team was very open about where they saw the problems with the analysis, what work needs to be done, and what they are doing to resolve the issues. The Peer Review group identified the same issues and provided recommendations / suggestions on how to address the issues. In most instances the Transport Analysis team was already working along the lines that the Peer Review group suggested. All identified issues are being addressed. The Peer Review group was encouraged to help determine the priorities of the recommendations and which ones to implement and to what extent. It was suggested that the Peer Review group provide prioritized recommendations to the Transport Analysis team in order to assure that they are focused on the engineering problem at hand and support RTF.

*It should be noted that the SSP has determined that it will not utilize any Lift-off Debris Transport Analysis results in the current STS-114 debris flight rationale. While the effort to date is considered a significant technical achievement, it is currently only good for qualitative assessment. The Lift-Off DTA peer review is in concurrence with this posture. The wind and gravity driven LODTA mechanisms are enveloped by aerodynamic DTA for debris sources present in flight. Plume driven mechanisms are not enveloped by ascent DTA. Trends indicate that plume driven debris must be avoided. The SSP has assessed and mitigated to the most practical extent the potential liftoff debris sources (e.g. pad rust*

*& scale). Liftoff debris is to be included in the integrated hazards with controls and mitigations specified and will be considered as an accepted risk (remote/catastrophic) for STS-114 RTF. This SSP position on Lift-Off debris sources is being assessed as part of the 05-010-E ITA to Peer Review the Flight Rationale for Expected Debris.*

Monte-Carlo / Probabilistic DTA Peer Review (4) – NASA JSC – Dec. 15-16, 2004

As the debris flight rationale methodology evolved, a calculation of the Capability over Environment (C/E) was established for foam and ice debris impacts on the Orbiter RCC (WLE & nose cap). Worst-on-worst calculations of C/E were established. These calculations resulted in negative debris impact certification margins for the Orbiter RCC. The SSP sought to more realistically apply the uncertainties using a Monte-Carlo DTA methodology. The peer review team evaluated the Monte-Carlo based DTA and uncertainty tools and established the applicability for supporting the STS-114 flight rationale. Issues, limitations, and necessary modifications were identified. Additionally, the peer review team addressed the recent development of a new probabilistic DTA methodology. Specific findings and recommendation charts presented to the SSP SE&I office are included in Appendix E. Thirty-Five (13 major and 22 secondary) findings and subsequent recommendations were reported to the SSP SE&I office.

The peer review team concluded that progress on the Monte-Carlo tools had been substantial and that they should support STS-114 debris flight rationale (given implementation of the Peer Review recommendations) for foam on RCC. It was noted that the current work was a major step in the direction previously recommended (from Peer Review 1 & 2). The uncertainty quantification captured in the Monte-Carlo DTA is feasible, however a caution was noted – It can be misleading to overlay a Monte-Carlo scheme on a deterministic (worst-on-worst) approach. It was recommended that the focus of DTA efforts be turned towards other debris sources (e.g., ice) at this time. The probabilistic techniques were deemed very promising and further development was encouraged. However, this probabilistic work should not be allowed to interfere with completing the Monte-Carlo analysis for other debris materials. The probabilistic methodology should focus development towards adding credibility in problem debris areas.

*It should be noted that both the Monte-Carlo DTA and a developing probabilistic DTA are now being employed by the SSP in developing debris flight rationale. The Monte-Carlo DTA was used extensively in defining the "Best Estimate" C/E values. These C/E calculations are now to be used only as an indicator and not as stand alone flight rationale. For those cases with "Best Estimate" C/E values below 1.5, the probabilistic DTA is being applied. This updated probabilistic DTA is being assessed as part of the 05-010-E ITA to Peer Review the Flight Rationale for Expected Debris, with direct involvement and review by the NESC.*

# 7   Lessons Learned

N/A

# 8   Definition of Terms (as required)

| | |
|---|---|
| Corrective Actions | Changes to design processes, work instructions, workmanship practices, training, inspections, tests, procedures, specifications, drawings, tools, equipment, facilities, resources, or material that result in preventing, minimizing, or limiting the potential for recurrence of a problem. |
| Finding | A conclusion based on facts established during the assessment/inspection by the investigating authority. |
| Lessons Learned | Knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure. A lesson must be significant in that it has real or assumed impact on operations; valid in that it is factually and technically correct; and applicable in that it identifies a specific design, process, or decision that reduces or limits the potential for failures and mishaps, or reinforces a positive result. |
| Observation | A factor, event, or circumstance identified during the assessment/inspection that did not contribute to the problem, but if left uncorrected has the potential to cause a mishap, injury, or increase the severity should a mishap occur. |
| Problem | The subject of the independent technical assessment/inspection. |
| Recommendation | An action identified by the assessment/inspection team to correct a root cause or deficiency identified during the investigation.  The recommendations may be used by the responsible C/P/P/O in the preparation of a corrective action plan. |
| Root Cause | Along a chain of events leading to a mishap or close call, the first causal action or failure to act that could have been controlled systemically either by policy/practice/procedure or individual adherence to policy/practice/procedure. |

# 9   Minority Report

None

## APPENDICES

A. Initial DTA Peer Review – Findings & Recommendations – Charts as presented to SSP SE&I office on Oct. 1, 2003.

B. LH2 Flange Foam Peer Review – Findings & Recommendations – Charts as presented to SSP SE&I office on Feb. 28, 2004.

C. Letter dated April 20, 2004 from C. Bidwell to NESC summarizing the LH2 Flange Foam DTA Peer Review and his observations

D. E-mail dated Nov. 18, 2004 from D. Dumbacher summarizing his observations regarding the Lift-Off DTA Peer Review

E. Monte-Carlo/Probabilistic DTA Peer Review – Findings & Recommendations – Charts as presented to the SSP SE&I office, Dec. 16, 2004.

# Plan Approval and Document Revision History

| Approved: | Original signature on file | 5-16-05 |
|---|---|---|
| | NESC Director | Date |

| Version | Description of Revision | Author | Effective Date |
|---|---|---|---|
| 1.0 | Initial Release | Steve Labbe | 5-16-05 |

# Initial DTA Peer Review
# - Findings & Recommendations -

## TEAM CHARTER

*Provide technical review of the Space Shuttle Program debris transport process to identify strengths and weaknesses in the analysis process and provide recommendations on how to increase the accuracy and completeness of the process.*

❖ *TRANSPORT PROCESS BEGINS AS DEBRIS LEAVES SOME PART OF THE SPACE CRAFT*
❖ *RATIONALE BEHIND THE DEBRIS FAILURE TO STAY ATTACHED AND THE EFFECT OF THE FOAM IMPACT IS NOT PART OF THIS REVIEW*

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## DEBRIS TRANSPORT TEAM PEER REVIEW

*October 1, 2003*

**Bass Redd (Retired JSC)**
**Mark Seaford (MSFC)**
**Steve Bauer (LaRC)**
**Chris Nagy (DFRC)**
**Jeff West (MSFC)**
**Ethiraj Venkatapathy (ARC)**
**Basil Hassan (Sandia)**
**Don Ward (Retired TAMU)**

# Initial DTA Peer Review
## - Findings & Recommendations -

### DEBRIS TRANSPORT PEER REVIEW

- **OVERALL IMPRESSIONS**
  - *LOTS OF GOOD CFD WORK*
  - *PROBLEM IS PROBABILISTIC*
  - *FIDELITY OF MODELS IS APPROPRIATE*
  - *EFFORT IS COMMENDABLE*
- **BETTER FOCUS NEEDED ON**
  - *COMPLETENESS OF THE PROCESS*
    - ◆ SCHEDULE NEEDS
    - ◆ SPECIFIC GOALS FOR DEBRIS TRANSPORT TEAM
  - *TOOL TWEAKS*
    - ◆ INPUTS
    - ◆ OUTPUTS AND TIMELINESS

### OVERALL IMPRESSIONS

- **THE OVERALL DEBRIS PROBLEM IS PROBABILISTIC IN CHARACTER, YET TRANSPORT TOOLS AVAILABLE ARE LARGELY DETERMINISTIC**
  - *PROBLEM IS EXTRAORDINARILY COMPLEX*
  - *DETERMINISTIC ANALYSIS PROBABLY COMMUNICATES BEST*
- **CFD TOOLS FOR TRANSPORT ARE APPROPRIATE**
  - *MULTIPLE LEVELS OF FIDELITY IS GOOD APPROACH*
  - *TEAM IS USING BEST TOOLS AVAILABLE*
  - *INTERFACE WITH CFD EXPERTS IS IN PLACE*
- **SENSITIVITY ANALYSIS OF MODEL ASSUMPTIONS AND INPUTS IS INCOMPLETE**
- **VALIDATION OF MODELS IS INCOMPLETE**

### RECOMMENDATIONS FOR SENSITIVITY ANALYSIS

**QUANTIFY EFFECTS ON IMPACT CHARACTERISTICS FROM:**

- **MODEL ASSUMPTIONS ($C_L = 0$, TUMBLING $C_D$)**
- **INITIAL CONDITIONS**
  - *ASCENT TRAJECTORY*
  - *DEBRIS TRANSPORT (SIZE, VECTOR, ETC.)*
- **GEOMETRIC FIDELITY AND COMPLEXITY OF PHYSICS MODEL**

### RECOMMENDATIONS FOR CONTINUED MODEL VALIDATION

- **INPUT MODELS**
  - *DEBRIS PARTICLE AERODYNAMICS*
  - *CFD FLOW FIELD PREDICTIONS*
    - ◆ VALIDATION IN TERMS OF VELOCITY?
- **DEBRIS TRANSPORT TRAJECTORY**
  - *SURVEY/UTILIZE EXISTING EXPERIMENTAL DATA*
  - *EMPHASIZE STS FLIGHT TEST CASES*
- **EXPECT TO ITERATE**

# Initial DTA Peer Review
## - Findings & Recommendations -

## RECOMMENDATIONS ON FURTHER MODEL DEVELOPMENT

- **USE AND FURTHER DEVELOP A WORST-ON-WORST ANALYSIS TO OBTAIN MAXI-MUM RANGE OF IMPACT CONDITIONS**
  - *IDENTIFY CRITICAL SOURCES OF DEBRIS*
  - *FOCUS AND GUIDE MID- AND HIGH-FIDELITY MODELS*
- **CONTINUE WITH PROPOSED CODE IMPROVEMENTS**
  - *TURNKEY COUPLED 6-DOF (ARC CODE)*
  - *UNCOUPLED 6-DOF (MORE EFFICIENT)*

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## CONCLUSIONS

- **DEBRIS TRANSPORT TEAM HAS DONE A REMARKABLE JOB**
- **GIVEN THE CURRENT ENVIRONMENT, APPROPRIATE BALANCE BETWEEN URGENCY AND FIDELITY HAS BEEN ACHIEVED**
- **PLANNED ENHANCEMENTS AND VALIDATION WILL IMPROVE RESULTS**
- ***MORE MUST BE DONE BEFORE RETURN TO FLIGHT – TRANSPORT TEAM IS READY TO ACT***

8
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## CONCERNS WITH OVERALL DEBRIS PROCESS

- **TRANSPORT TEAM EXPECTATIONS**
  - *DEBRIS GENERATOR AND DAMAGE TOLERANCE TEAM INTERFACES*
- **IMPROVED SYSTEM ENGINEERING INTEGRATION AND COMMUNICATION COULD RAISE TRANSPORT TEAM EFFECTIVENESS**

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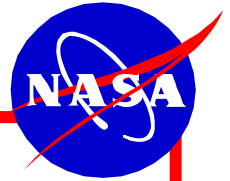
# Debris Peer Review 2

Panel Members

Bass Redd, Chairman

Del Freeman

Aldo Bordano

Rick Barton (USA)

Steve Bauer (NASA Langley

Mark Seaford(NASA Marshall)

Chris Nagy (NASA Dryden)

Johnson Wang (Aerospace Corporation)

Colin Bidwell (NASA Glenn)

Jeffrey Payne (Sandia)

Francisco Canabal (NASA Marshall)

Don Ward (Texas A&M)

Ethiraj (Raj) Venkatapathy (NASA Ames)
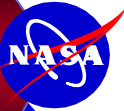
*February 26, 27 2004*

- Charter for Review Panel

  *PROVIDE TECHNICAL REVIEW OF THE SPACE SHUTTLE PROGRAM DEBRIS TRANSPORT PROCESS TO IDENTIFY STRENGTH AND WEAKNESSES IN THE ANALYSIS PROCESS AND PROVIDE RECOMMENDATIONS ON HOW TO INCREASE THE ACCURACY AND COMPLETENESS OF THE PROCESS*

  - *THIS REVIEW COVERS ONLY THE $LH_2$ FLANGE FOAM DEBRIS TRANSPORT -- NOT DEBRIS SOURCES OR DEBRIS IMPACT ASSESSMENT*

# General Comments
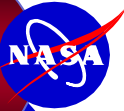
- Bob Ess, Ray Gomez, and the NASA/USA-Boeing team have done a good job developing an approach to resolve a difficult RTF issue

- The tools/processes being developed must meet both RTF and operational needs
  - *Engineering methods (all fidelities) must be further refined*
  - *Continued development of the Cart3D 6-DOF approach will enhance this capability*

# LH$_2$ Debris Transport Finding
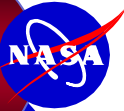
- Current transport methodology process is adequate for definition of extent of ET LH$_2$ flange (-96$^o$<$\Phi$<96$^o$) foam debris sources which will impact the RCC

- The recommendation to eliminate the LH$_2$ flange foam debris source is reasonable and prudent based on the current understanding of debris size/shape and debris pop-off – WE CONCUR

# LH$_2$ Flange Foam Debris Observations

- $\Delta\alpha$ and $\Delta\beta$ uncertainties cause similar impact dispersions and should also be expanded to include $\Delta q$ in future analyses

- Particles that impact the SRB or tank are taken out of the analysis; reflected particle trajectories should continue to be traced

- Some method of impact probability should be developed for program management decisions

- The Ames CART3D, 6DOF analysis will help our understanding greatly
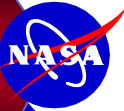
- STS27 and STS87 are the more relevant cases for demonstrating the Debris Transport engineering approach.

  - *The results suggest that the debris analysis tools are able to reproduce impact pattern and the results agree with reasonable accuracy*

  - *However, the input shape is far different from that used in the computations; this may be part of the reason the input velocity had to be adjusted upward*

  - *Recommendation:  The higher fidelity method (CART3D 6DOF) should be run for the purpose of verifying STS27*

- STS-26R and STS107 cases deal with a single impact and are most difficult cases to solve.
  - *The simulation input parameters needed to reproduce the impact location is not known.*
  - *The current "engineering" fidelity method neither has the right drag model nor accounts for the lift forces.  Hence the observed inconsistency in comparison.*
  - *Recommendation:  The higher fidelity method (CART3D 6DOF) should be applied to the STS26 and STS107 cases*
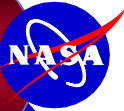
- Observation:  The results for $M$/$\alpha$/$\beta$/q variations addressed only nominal flight corridors.  The design corridors are considerably larger.

- Recommendation:  Run cases at the boundaries of the design envelope.

# CART3D Code Utilization

- Ames coupled (CARD3D 6-DOF) development and demonstration is impressive. The case studies presented demonstrating the fidelity of the method give credibility to the predictions.

- The drag model prediction and comparison with data for tumbling cube comparison is appropriate and reasonable. For $M < 0.5$, the lack of comparison of the drag needs to be addressed.

- Recommendation:  Proceed to complete the CART 3D 6-DOF development and apply it to analyze RTF debris transport requirements

- Recommendation:  Use Ames capability to characterize debris aerodynamic and provide this to the debris transport method to improve the prediction fidelity

# Recommendations

- Proceed to complete the CART 3D 6DOF development and apply it to analyze RTF debris transport requirements

- Define an approach to verify/validate the debris transport process

  - *Validate aero with wind tunnel/ballistic range tests using representative debris (shape, mass)*

  - *Demonstrate the process with validated aero*

  - *Explore ways to quantify uncertainty and risk embedded in the transport analyses generated*

- Ultimately, program decisions should be made with a known degree of uncertainty
    - *A systems approach (all elements) need to individually consider how best quantify uncertainty (how much conservatism is inherent in the analysis)*
    - *The DAT analysis involves considerable uncertainty in its assumptions, in input conditions, and aerodynamics*
    - *The DAT must evolve activities to support this system-wide quantification effort*
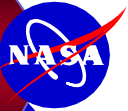
# BACKUP CHARTS FOLLOW

National Aeronautics and
Space Administration

**John H. Glenn Research Center**
**Lewis Field**
Cleveland, Ohio  44135-3191
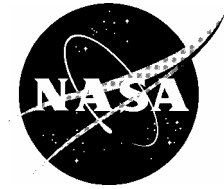
April 20, 2004

Reply to Attn of:     5840

**TO:**          NESC Office

**FROM:**      5840/Colin Bidwell, NESC Representative

**SUBJECT:**   SSP Debris Transport Peer Review (Houston, Feb. 26-27).

I was asked to represent NESC in a Peer Review of The Space Shuttle Debris Program in Houston Feb. 26-27. The charter of the peer review committee was to provide technical review of the Space Shuttle Program Debris Transport Process to identify strength and weaknesses in the analysis process and provide recommendations on how to increase the accuracy and completeness of the process. This Peer Review was an interim peer review which concentrated on the LH2 flange foam debris transport which has recommended a redesign of the main shuttle tank and consequently a subsequent delay in return to flight. The peer review committee found the analysis process reasonable and concurred with their findings that the shuttle tank be redesigned.

The committee felt strongly that more physics should be added into the Debris Trajectory Program (i.e. Lift, Pitching Moment Equations) and that more validation should be done. It was left to the Transport Team to determine the method of validation. The committee also felt that more work should be done with Cart3D in validating the values used for initial conditions in the Debris Trajectory Program (i.e. initial particle velocity vector) which were used to compensate for lack of physics in the program (i.e.  Lift, Pitching Moment Equations) and in generating Lift, Drag and Pitching Moment Coefficients for an improved physics model in the Debris Trajectory Program.

My feelings were similar to the committees in that I would like the Debris Trajectory Program to have an updated physics model.  I think that this program should be the work horse of the debris transport effort. I also believe strongly that experimental data should be generated for the class of particles to be simulated. I believe I differed from the committee in my level of confidence in using Cart3D to generate the lift, drag and pitching moment data for the class of particles to be simulated. I have doubts about using the Euler based Cart3D program in the subsonic regime to generate drag for these particles. The particles investigated typically were decelerated to subsonic speeds within 10-20 feet of release. I was also glad to hear that a higher fidelity tool with viscous effects was also being used (Overflow) to simulate the 6 DOF problem. The committee felt it was important to generate experimental data in addition to using Cart3D. I think it is necessary to generate the data.

In general a lot of good work was done by a group of talented people. There were a lot of unknowns in the process but I think the way in which they were handled provided a useful, conservative answer. I was in agreement with the findings from the committee and the Transport Team that the shuttle tank be redesigned to eliminate the potential LH2 flange foam debris source.

Colin Bidwell
Aerospace Engineer
NASA Glenn Icing Branch
216-433-3947

# Unknown

**From:** Dumbacher,Dan [dan.dumbacher@nasa.gov]
**Sent:** Thursday, November 18, 2004 1:54 PM
**To:** LABBE, STEVEN G. (STEVE) (JSC-ZE) (NASA)
**Cc:** 'Garcia, Robert '; 'Charles.E.Harris@nasa.gov'; HAMILTON, DAVID A. (DAVE) (JSC-ZE) (NASA); 'Jones, Preston '; 'West, Jeff '; 'Haynes, Davy '; 'Tiller, Bruce '; 'Turner, Jim '; 'Dougherty, Sam '; 'Nesman, Tom '; 'Byrd, Thomas '
**Subject:** RE: Debris Transport Peer Review

**Importance:** High

Steve -

Below are my observations from the Lift off Debris Transport Peer Review.

First, I must admit that I am not an expert by any measure on the technical matters that have been discussed during the last couple of days. From my experience in systems engineering, Space Shuttle Main Engine development and operations, experimental launch vehicle programs, and exploration activities it is apparent to me that the technical issues are being identified and worked by a very capable team, including the peer review group.

This is an extremely difficult problem to address and no one has attempted to develop as much technical rigor into this analysis in the past. The team should be commended for their attention to detail, identification of technical issues, and open communication among the team and the peer review group. From my standpoint, Jeff West and his team have done yeoman's work to get to this point given the short period of time they have been working the problem.

Throughout the discussion, the Transport Analysis team was very open about where they saw the problems with the analysis, what work needs to be done, and what they are doing to resolve the issues. It appears to me that the Peer Review group identified the same issues and is providing recommendations / suggestions on how to address the issues.
The Transport Analysis team was very open to the comments and suggestions provided by the Peer Review group, and in most instances were already working along the lines that the Peer Review group suggested. I did not see any issues that were identified but glossed over. All identified issues are being addressed. Unfortunately, I am personally unable to determine if additional issues are unidentified.
As the effort progresses, the Peer Review group should stay engaged to assure the success of the analysis.

A comment I have provided to the Peer Review group is that they can help determine the priorities of the recommendations and which ones to implement and to what extent. I suggested that the Peer Review group provide prioritized recommendations to the Transport Analysis team in order to assure that they are focused on the engineering problem at hand. The Peer Review group agreed with this recommendation and will prioritize their recommendations.  It is essential that the status / progress / open work be reviewed to determine what is needed to be done prior to Return-to-Flight.

In summary, this was an excellent review with much forward work to be accomplished, and the team (Transport Analysis & Peer Review) is actively working the problem and associated issues to meet the needs for Return-to-Flight.

Should you need anything else from me, please do not hesitate to contact me.

Sincerely,

Dan Dumbacher

At 7:48 AM -0600 11/17/04, LABBE, STEVEN G. (STEVE) (JSC-ZE) (NASA) wrote:
>Robert & Dan,
>

>Thanks for your support on such short notice.  As discussed with
>Robert, it is unlikely that many (any?) debris limiting cases will fall
>out of the lift off debris environment (when compared to the ascent environment).
>
>However, the NESC is interested in penetrating the programs technical
>rigor and depth of the analysis through the program's peer review
>process.  Dan's role should be to ensure that the liftoff debris peer
>review is satisfactory and that any technical issues are identified
>with a plan to be resolved by the March 2005 DCR time frame.
>
>Direct participation in the boards deliberations (open & "private)
>would be best.
>
>Thanks again,
>
>Steven G. Labbe
>Chief, Applied Aeroscience & CFD Branch - Mail Code EG3 NESC Discipline
>Expert for Flight Sciences - Detailed - Mail Code ZE NASA Johnson Space
>Center
>2101 NASA Parkway
>Houston, TX 77058-3696
>Phone (281)483-4656 / Mobile (281)989-5453 / Fax (281)483-3861
>
>-----Original Message-----
>From: Dumbacher,Dan
>To: Garcia, Robert
>Cc: Jones, Preston; LABBE, STEVEN G. (STEVE) (JSC-ZE) (NASA); West,
>Jeff; Haynes, Davy; Tiller, Bruce; Turner, Jim; Dougherty, Sam; Nesman,
>Tom; Byrd, Thomas
>Sent: 11/16/2004 4:37 PM
>Subject: Re: Debris Transport Peer Review
>
>Robert -
>
>Thanks for the info. I will have to leave for a 10 AM meeting tomorrow
>for a couple of hours, and I will have to leave Thursday for a 2:30
>meeting.
>
>If there are problems, please let me know.
>
>Dan
>
>At 3:59 PM -0600 11/16/04, Garcia, Robert wrote:
>>Dan, thanks for helping us on such short notice.  The debris transport
>>peer review meeting is Wednesday and Thursday (November 17 & 18), at
>the
>>following times:
>>
>>Time:  (Nov. 17) - 8:00 AM - 5:00 PM
>>        (Nov. 18) - 8:00 AM - 3:30 PM  (may end earlier)
>>
>>The location for the meeting is:   United Space Alliance; 555 Discovery
>>Drive
>>
>>The first attachment is a map to the meeting location (I hate maps
>where
>>North does not point up)
>>If you have any trouble getting in or finding the room, please call:
>>
>>Renea Johnson
>>USA/Huntsville
>>Program Integration
>>256-971-2680
>>256-971-2683 - Fax
>>
>>The second attachment is the tentative agenda and the membership of

2

```
>>the peer review board. The peer review board has a "private" meeting
>>Thursday morning to formulate their report back to program. Let me
>>know if you would like to sit in on that and I can see if it is o.k.
>>with
>Tom
>>Byrd (he is the shuttle integration lead on all of this).
>>
>>Roberto Garcia
>>Chief, Propellant Delivery Fluids Branch ER42, Marshall Space Flight
>>Center
>>256-544-4974
>>roberto.garcia-2@nasa.gov
>>
>>
>>Attachment converted: Macintosh HD:MAP debris review.pdf (PDF /CARO)
>>(002F11FA)
>>Attachment converted: Macintosh HD:Peer Review Agenda.ppt
>>(SLD3/PPT3) (002F11FD)
```

# MONTE CARLO DEBRIS TRANSPORT ANALYSIS PEER REVIEW

## Boeing – Houston

December 15-16, 2004

# CHARGE - PRIMARY

- **UNDERSTAND AND EVALUATE MONTE CARLO-BASED TRANSPORT AND UNCERTAINTY TOOLS**
  - *Are they good enough to underpin STS-114 flight rationale?*
  - *Will they support May 2005 launch?*
- **Recommend appropriateness of tools**
- **Identify issues, limitations, and necessary modifications**

# CHARGE - SECONDARY

- **UNDERSTAND AND EVALUATE PROBABILISTIC METHODOLOGY**

- **CONSIDER READINESS OF PROPOSED TECHNIQUE**

  - *Can it be developed in time to meet flight schedule?*

  - *What improvements are necessary and/or desirable?*

# PANEL MEMBERS

- **Bass Redd**
- **Rick Barton**
- **Colin Bidwell**
- **Mike Weaver**
- **Basil Hassan**
- **Dick Heydorn**
- **Steve Labbe**

- **Edgar Medina**
- **Jim Rogers**
- **Mark Seaford**
- **Ben Thacker**
- **Bill Vesely**
- **Don Ward**
- **Jeff West**

*December 15-16, 2004*

# OVERVIEW

- **PROGRESS ON MONTE CARLO TOOLS HAS BEEN SUBSTANTIAL – THEY SHOULD SUPPORT STS-114 FLIGHT RATIONALE**
  - *CURRENT WORK IS MAJOR STEP IN DIRECTIONS PREVIOUSLY RECOMMENDED*
  - *COMPLETE TOOLS BY ADDRESSING ISSUES/RECOMMENDATIONS OF PEER REVIEW*
  - *FOAM CASE DATA SUGGEST TOOLS ARE ADEQUATE PENDING FINAL VALIDATION*
    - ◆ **MUST carefully articulate rationale for assumptions**
    - ◆ **Should use sensitivities to guide refinements**
- **MUST FOCUS ANALYSIS EFFORTS FOR OTHER TYPES OF DEBRIS NOW**
- **UNCERTAINTY QUANTIFICATION IS FEASIBLE**
  - *APPROACH APPEARS TO BE READILY EXTENSIBLE TO OTHER TYPES OF DEBRIS*
  - *BEWARE – IT CAN BE MISLEADING TO OVERLAY A "MONTE CARLO" SCHEME ON A DETERMINISTIC APPROACH (Worst-on-Worst)*
- **PROBABILISTIC TECHNIQUES ARE VERY PROMISING**

# OVERALL RECOMMENDATIONS

- **COMPLETE (LEVEL 3) ANALYSIS FOR OTHER TYPES OF DEBRIS NOW**
  - *Highlight troublesome issues to other elements*
  - *May highlight requirement for Probabilistic Approach (Level 4)*
  - *Reexamine/justify choice of MOEs*

- **PURSUE PROBABILISTIC APPROACH**
  - *Do not allow this work to interfere with completing analysis for other debris materials*
  - *Focus development of this approach on adding credibility in problem areas*

# ISSUES & RECOMMENDATIONS

**Ben Thacker**

- ## ISSUE
  - *The terminology currently being used by the DTA team causes confusion*

- ## RECOMMENDATION
  - *Use accepted definitions, for example:*
    - ◆ Uncertainty-**A potential deficiency in the modeling process that is due to inherent variability (irreducible uncertainty) or lack of knowledge (reducible uncertainty).**
    - ◆ Uncertainty Quantification-**The process of characterizing all uncertainties in the model, and quantifying their effect on the simulation outcomes.**
    - ◆ Probabilistic Analysis-**An analysis methodology that treats model inputs as random variables**
  - *Side notes*
    - ◆ Probabilistic Analysis **is a subset of** Uncertainty Quantification
    - ◆ **Monte Carlo is a** Probabilistic Analysis **method**

# ISSUES & RECOMMENDATIONS
## Jeff West

## ISSUE

- *The civil-service Ascent DTA team started as Aerospace Engineering practitioners with CFD experience. Over the past 23 months they have become debris-ologists. They are now addressing uncertainty quantification and probabilistic risk assessment leading to flight rationale. They still have to be AE's and debris-ologists. The CS team has begun Probabilistic Approach with a passion along logical lines. It was pointed out how early these efforts are in the learning process of Probabilistic Approach*

- *The Probabilistic Approach work is singularly important. Is it reasonable to expect this overworked team to develop graduate-level insight and ability in Probabilistic Approach with on the order of weeks notice?*

## RECOMMENDATIONS

- *The CS Ascent DTA team needs augmentation with mature probability analysis to perform integration, oversight and communication functions. Or else, enough time to grow into the role….*

- *The (level 4) probabilistic methodology appears to be on the correct track, but is not yet ready to support an RTF rationale. This should not be the last Peer Review on this subject.*

# ISSUES & RECOMMENDATIONS

**Ben Thacker**

## ISSUE

- *Wrapping a Monte Carlo algorithm around a deterministic model is inaccurate.*
  - ◆ **Deterministic models typically contain built-in conservative assumptions that must be removed for the probabilistic model to produce credible results.**

## RECOMMENDATION

- *Critically review the debris transport model (e.g., inputs, theories, algorithms, strate-gies, etc.) for conservative assumptions.*
  - ◆ **Nominal material properties may contain FOS, complex loadings may be overly simplified, or failure conditions may be overly conservative (e.g., "Capability" in the butterfly curves)**

# ISSUES & RECOMMENDATIONS

**Ben Thacker**

## ISSUE

- *Epistemic (reducible) uncertainties can be quite large and have a significant effect on probabilistic results.*

## RECOMMENDATION

- *Use structured techniques (PIRT or QFD) to identify and rank all physical phenomena and model requirements and ensure that all are represented in the model*
- *Employ uncertainty modeling techniques to properly represent vague and non-specific model inputs*
- *Include statistical uncertainty (insufficient data) as additional inputs to the probabilistic model. These inputs will produce confidence bounds on the computed probability and allow risk-informed decisions*

# ISSUES & RECOMMENDATIONS

**Ben Thacker**

## ■ ISSUE

- *Probabilistic sensitivities reflect the importance of a variable's physical (deterministic) and stochastic (uncertain) importance and would be a highly valuable input for RTF decisions*

## ■ RECOMMENDATIONS

- *In addition to statistics currently being computed from the Monte Carlo samples, also compute probabilistic sensitivities (e.g., dp/dmu, dp/dsig, dp/df).*

- *These sensitivities can also be computed for all other probabilistic analysis methods.*

# ISSUES & RECOMMENDATIONS

**Mark Seaford**

## ■ ISSUE

- **Monte Carlo-based transport uncertainty assessment results for 12 end to end foam on RCC cases appear to preclude the need for refined higher order probabilistic methods.**
  - ◆ **This finding is entirely dependent on the adequacy of current input data.**

## ■ RECOMMENDATION

- **Assess adequacy of input data**

# ISSUES & RECOMMENDATIONS
### Mike Weaver

## ■ ISSUES

- ● *Breakup of debris is neglected in the method-ology. Counter examples to doing so are:*
  - ◆ **Bipod ramp foam from STS-107**
  - ◆ **Foam divots of dubious structural integrity shown on chart 16 of "MC Input"**
  - ◆ **Relatively high KE sensitivity to volume and drag change (e.g. chart 7 of "MC Input")**

## ■ RECOMMENDATION

- ● *Examine KE sensitivity to simultaneous change in volume and drag, associated with breakup. Use the results to support or refute the neglect of debris breakup*

# ISSUES & RECOMMENDATIONS

**Jim Rogers**

- ## ISSUES
  - *While integration is dependent on elements for input data, they are still responsible for fully understanding all input and demanding that adequate input is provided.  Currently some important inputs have no uncertainty given and some are poorly defined.*

- ## RECOMMENDATION
  - *All important inputs should be given with uncertainties in a standard form*

# ISSUES & RECOMMENDATIONS

**Jim Rogers**

## ISSUE

- *Some input parameters had uncertainties added or increased in an effort to be "conservative".  Increasing spread may actually reduce probability of a debris hit*

## RECOMMENDATION

- *Adding extra uncertainty should be avoided*
- *Sensitivity analysis should be performed to find the direction of conservancy*

# ISSUES & RECOMMENDATIONS

**Richard Heydorn**

- **ISSUE**
  - *Characterization of uncertainty*
- **RECOMMENDATION**
  - *The uncertainty in the Monte Carlo model should be obtained from the historical records as was the validation check. The historical record of hits on the Orbiter is a basic piece of information that tells us how realistic we are in our prediction process. But the historical record only represents a sample of what can happen and therefore the uncertainty represented by that sample should be reflected in the Monte Carlo prediction.*
  - *Historical records of hits on the Orbiter should be used to match the outputs of the Monte Carlo model. One cannot make a point by point correspondence of a Monte Carlo prediction with historical hits on the Orbiter, but one can compare the distribution of hits the Monte Carlo model would predict with the actual hit data.*
  - *To compare hit distributions with the Monte Carlo, one can look at two dimensional (X,Y) distributions over selected areas on the Orbiter and test some statistical hypothesis, at some level, that these distributions are in fact equal.*

# ISSUES & RECOMMENDATIONS
**Basil Hassan**

■**ISSUE**

- *The work being done on the Probabilistic Approach (Level 4) by Boeing Co. is obviously a work in progress, but the team is systematically working to address improvements in the methodology. It is believed that there is more rigor in this approach than the Uncertainty Quantification Approach (Level 3).*

■**RECOMMENDATIONS**

- *Every effort should be made to use this method-ology to verify the Uncertainty Quantification Approach (Level 3). Additional scenarios should be tested to build confidence in this approach.*

# ISSUES & RECOMMENDATIONS

**Colin Bidwell**

## ■ ISSUE

- *The current "Cone" methodology may not be generating the maximum possible kinetic energies for trajectories that traverse the region near the orbiter fuselage. These particles may experience flow velocities that are higher than those of the "zero" lift trajectories. This could result in higher deceleration rates and higher kinetic energies at impact for these trajectories.*

## ■ RECOMMENDATION

- *Generating a few trajectories in this near field region using the Cart3D 6-DoF calculations to investigate the cross-flow characteristics in this region*
- *Calculating a number of trajectories using the Debris code with time dependent parameter variations from the 6 DOF calculations to validate the "Cone" analysis*
- *Calculating 1-D trajectories using flow-field properties along impact trajectories generated using the "Cone" methodology to improve kinetic energy prediction. The impact trajectories would be generated assuming constant percentage cone radius from the impact point back to the release point. This technique would compensate for flow-field variations from the "zero" lift trajectory*

# ISSUES & RECOMMENDATIONS
### Steve Labbe

- **ISSUE**
  - *Inputs, Inputs, Inputs! – Critical values, mean, min/max, plausible bounds, uncertainty levels and distribution types need to be finalized*

- **RECOMMENDATIONS**
  - *SE&I should conduct a technical workshop/forum bringing the critical contributors to the table to finalize.*
    - Monte-Carlo must be consistent with interfaces (ET inputs & Orbiter impacts) – Modeling results providing the right data – are these being supplied?
    - If emphasis would change could it result in modification to the DTA MC process?
    - NOT A PEER REVIEW.

# Backup Charts

# ISSUES & RECOMMENDATIONS
## Steve Labbe

- ## ISSUE
  - *Transport of "debris flux" downstream in BUMPER is limited to a "small" distance so flowfield effects are not neglected.  Valid?*
  - *Orbiter WLE RCC panel capability numbers are a function of impact location*

- ## RECOMMENDATIONS
  - *Plane convergence study or some such thing*
  - *Incorporate WLE impact location capability into the Global Transport PRA model*

# ISSUES & RECOMMENDATIONS
### Basil Hassan

## ISSUE
- *The team states that "structured overset and block zonal grid systems" is a limitation. This is not correct.*

## RECOMMENDATION
- *While the structured overset and block zonal grid systems are more difficult to use from a grid generation standpoint (compared to unstructured grid methods), these techniques are more mature and have been more extensively validated.*

# ISSUES & RECOMMENDATIONS

**Basil Hassan**

## ISSUE

- *Team has done an adequate job of providing uncertainties in input parameters, given the sparse or incomplete information received from ET.  For the 11 debris release locations, they have computed favorable margins for all but one.*

## RECOMMENDATION

- *Given the uncertainties in some of these inputs, they may want to reverse analyze the problem by determining what range of input is required for no margin.   One input can be varied independent of others (keeping it physically relevant) to assess its sensitivity.*

# ISSUES & RECOMMENDATIONS

**Colin Bidwell**

## ■ISSUE

- *Using trajectory flux path vectors based on values from the Cart3D 6-DoF calculations for the impact trajectories generated from the "zero" lift trajectories does not seem well founded. It doesn't seem warranted and may cause misses in the BUMPER code due to the long extrapolation distances*

## ■RECOMMENDATION

- *A better method would to use the path angle and path velocity for impact trajectory based on a constant percentage distance from the "zero" lift trajectory*
- *I would like to see a single, streamlined, more consistent methodology which uses a single set of grids and impact locations for the analysis such as that used in the debris code*

# ISSUES & RECOMMENDATIONS
**Jim Rogers**

## ISSUE
- ### *Test data have shown that lift varies over time for a single particle.  The model currently picks a single lift value from a uniform distribution.  This will increase the debris footprint*

## RECOMMENDATION
- ### *Investigate using a more central uncertainty to account for the averaging affect of changing lift*

**Jim Rogers**

# ■ISSUE

- *Some input parameter (i.e. $C_D$) have had a uniform uncertainty applied that may exaggerate the actual variability.  This may reduce and the risk by spreading the debris footprint*

# ■RECOMMENDATION

- *Investigate whether uniform uncertainties have been used appropriately on all important inputs*

# ISSUES & RECOMMENDATIONS

**Jim Rogers**

## ■ ISSUES

- ● *Mass is an important input parameter. The input is currently given as a single "Maximum Expected" value. This value is not well defined and inadequate for an important input.*

## ■ RECOMMENDATION

- ● *Demand a characterization of mass uncertainty from the element.*

## ■ ISSUE

- ● *What question was addressed by first section yesterday?*
  - ◆ Uncertainty Analysis:  providing an interval about a calculated value in which the true value is expected to lie within with a certain confidence level or
  - ◆ What is the actual probability of a catastrophic event occurring by events that lie outside of the confidence interval above?

## ■ RECOMMENDATIONS

- ● *There is confusion by both presenters and reviewers on this question.  The two questions are separate and pains should be taken to ensure clarification in future communication.*

# ISSUES & RECOMMENDATIONS
## Jeff West

## ■ ISSUE

- ● *In traditional uncertainty analysis, sensitivity is measured by a partial derivative, the slope of a curve at a point due to a parameter change, instead of just result function variation due to possibly too large of a change in parameter.  For example, the change in Mach number of 2.75 +/-0.25 is not thought to be a realistic measure of uncertainty in the Mach number at a given MET.  Not rigorously conforming to the mathematical philosophy can lead to misleading conclusions. ref.(RG2, p13).*

- ● *See next slide for definition of sensitivity and related definitions of uncertainty magnification factor and uncertainty percentage contribution. It is no harder, and utilizes the same methodology, to calculate uncertainty sensitivity correctly than to calculate what was shown, which was bulk parameter response.*

# RECOMMENDATIONS

- *Consider the result, r, of a data reduction equation with J input variables, $x_i$*

$$r = r\left(x_1, x_2, \ldots, x_J\right)$$

- *The overall uncertainty in r is $U_r$*

$$U_r = \left[\sum_{i=1}^{J}\left(\frac{\partial r}{\partial x_i}\right)^2 U_{x_i}^2\right]^{\frac{1}{2}} \qquad UMF = \frac{x_i}{r} \cdot \frac{\partial r}{\partial x_i} \qquad UPC = \frac{\left(\frac{\partial r}{\partial x_i}U_{x_i}\right)^2}{\sum_{i=1}^{J}\left(\frac{\partial r}{\partial x_i}U_{x_i}\right)^2} * 100$$

- *The sensitivity of the result to uncertainty can be presented as the uncertainty magnification factor (UMF) and the uncertainty percentage contribution (UPC)*
  - ◆ If *UMF > 1*, *$Ux_i$* is magnified by the data reduction method
  - ◆ If *UMF < 1*, *$Ux_i$* diminishes

# ISSUES & RECOMMENDATIONS
## Jeff West

- **ISSUE**
  - *It is common for a result, r(x1,x2,…xn) to have parameter values (xn) that can each take on a range of values. At each specific parameter value, there exists an uncertainty in that value. An uncertainty analysis quantifies and propagates the uncertainties through the calculation. This distinction was not clear in the presentations, instead possible parameter ranges and uncertainties were lumped together into one range of values, which was propagated through the calculation to the result. It is expected to have a number of actual debris particles with different masses due to systematic differences in origin. To consider the lumped unknown as uncertainty seems to be simplistic and may lead to un-realization of benefit if the two were separated and considered separately. It may also be harder to communicate results if one lumps the two concepts into one.*

- **RECOMMENDATION**
  - *The uncertainty quantification task is on the right track and near complete. Some changes need to be made in the area of determining sensitivities and distinguishing between real uncertainties and real parameter variations. The Monte Carlo method of uncertainty propagation is required by the variety of uncertainty knowledge (or lack of) of the input to the debris transport model. A glaring need exists to perform Uncertainty quantification over the entire debris problem scope in which wholesale, un-defendable conservatism is identified and replaced with defendable conservatism. With this change, many more cases of closure with C/E methods will likely present themselves. Either that or wait on PRA process development below.*

# ISSUES & RECOMMENDATIONS

**Ben Thacker**

- ## ISSUE
  - *Model validation requires independence between the model simulation and the experiment*
- ## RECOMMENDATIONS
  - *Validation tests should be planned by both the modeler and experimenter to ensure precise boundary and initial conditions, and that relevant test results are collected.*
  - *The modeler should not know the results from the experiment until after reporting the results from the model simulation.*
  - *Model validation is the assessment of the degree of agreement between simulation and test; therefore, uncertainties must be quantified in both the model and the experiment.*

# ISSUES & RECOMMENDATIONS

**Ben Thacker**

- ## ISSUE

  - *Assuming a uniform probability distribution because "no data is available" is not technically defensible*

- ## RECOMMENDATIONS

  - *If it is known (or even just believed) that a model input contains inherent variability, it is defendable to model that input as a random variable. However, the distribution should not be arbitrarily assigned to be uniform.*

  - *Use models that allow the shape of the distribution to be given by the data (including subject matter expert opinion). Another option is to use methods such as Bayesian updating.*

# ISSUES & RECOMMENDATIONS
### Ben Thacker

## ■ ISSUE

- ● *A probabilistic analysis cannot consider uncertainties that are not identified and characterized in the model*

## ■ RECOMMENDATIONS

- ● *Identifying missing uncertainties in a model by:*
  - ◆ Careful construction of a conceptual model (via PIRT for example) before developing the mathematical and computational model.
  - ◆ Do not use (deterministic) intuition to select which variables will be random. Instead, use probabilistic screening analysis to identify important random variables.
  - ◆ After validating the model (comparing to experimental observations), critically hunt down all possible reasons for discrepancies in the comparison (even if deemed small).

# ISSUES & RECOMMENDATIONS

**Ben Thacker**

## ■ ISSUE

- *Monte Carlo Simulation (MCS) is well-suited for some problems (fast-running models, ill-behaved models, models with large numbers of random variables), but inefficient and inaccurate for small probabilities*

## ■ RECOMMENDATIONS

- *For sample sizes under 2000, Latin Hypercube Simulation (LHS) is effective.*

- *For sample sizes above 2000, efficient sampling or numerical probability integration methods should be used.*

- *The effects of parameter correlations can dramatically change the probabilistic results and should be included in the analysis.*

# ISSUES & RECOMMENDATIONS
### Ben Thacker

## ISSUE

- *Boeing has identified differences in assumptions regarding release location as the likely reason for discrepancies between the Boeing and NASA model*

## RECOMMENDATIONS

- *Investigate which modeling approach (worst case or uniform variation or other) is correct and resolve the discrepancy*

# ISSUES & RECOMMENDATIONS
### Ben Thacker

- **ISSUE**
  - *It appeared as though the uncertainties in the "high-fidelity" probabilistic model were being constructed using standard (normal) probability distributions because they are mathematically easy to deal with*

- **RECOMMENDATIONS**
  - *Uncertainties should be characterized from scatter in data and not on the basis of mathematical tractability. For example, the use of normal distributions to represent lift variability and panel projections was not justified on the basis of scatter in data.*
  - *Use tools such as random fields to represent spatial variability such as the distribution of debris impacting the RCC panels. The scale of fluctuation and autocorrelation parameters in these models can be fit to model the observed scatter in the data.*

## ■ ISSUE

- *The Monte Carlo Based Transport Uncertainty Methodology Appears Adequate to Identify Critical Debris Source Locations. The Priority for Further Higher Order Probabilistic Assessment of a Given Debris Source Location can be Determined by Using the Current Monte Carlo Based Transport/ Uncertainty Methodology.*

## ■ RECOMMENDATION

- *Continue efforts*

# ISSUES & RECOMMENDATIONS

**Mike Weaver**

- ## ISSUE
  - ● *The cross-range (lift) model neglects cross-range velocity in calculation of impact KE*

- ## RECOMMENDATIONS
  - ● *Quantify the cross-range component of KE, in order to support or refute its neglect*
    - ◆ The necessary data are already available from the NASA/ARC Cart3D 6-DOF data set
    - ◆ Also, work planned by Phil Stuart to integrate the Cart3D trajectories into the MC methodology can be directly applied to the recommended task

# ISSUES & RECOMMENDATIONS

**Don Ward**

## ■ ISSUE

- ● *Team is "drifting" toward MOE choice*
- ● *KE and impact velocity have become the "de facto" measurands of choice*
  - ◆ Danger: rationale for choice is not clearly stated
  - ◆ DTA team may be contributing to this drift

## ■ RECOMMENDATION

- ● *Establish and adhere to a logical, disciplined process for choosing MOEs*
  - ◆ Stop "drifting" by examining alternatives
  - ◆ Articulate rationale succinctly but completely

## ■ ISSUES (Flow-field Unsteadiness)

● *Unsteady flow effects are unquantified. The concern is that significant lateral flow might deflect debris into SSME nozzles (for example). Causes of unsteadiness include:*

◆ Start-up transients from SSMEs and SRBs

◆ Plume impingement on the MLP as the SSV rises

## ■ RECOMMENDATION

● *Quantify the time scales and velocity magnitudes associated with unsteady flow contributing to lateral motion of debris. Justify the use of steady-state flow-fields with these findings. Possible useful data from previous missile launches simulations; SSME start-up simulations*